TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 843

A SUMMARY OF RESULTS OF VARIOUS INVESTIGATIONS OF THE MECHANICAL PROPERTIES OF ALUMINUM ALLOYS AT LOW TEMPERATURES

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SUMMARY

The available sources of data on the mechanical properties of aluminum alloys at low temperatures are listed and a summary of the material to be found in each source is given. There is included a discussion of the results of recent tests of aluminum alloys at low temperatures made at the Aluminum Research Laboratories.

SOURCES OF DATA

1. Cohn, L. M.:
   Elek. u. Masch., vol. 31, May 1913

   Änderungen der physikalischen Eigenschaften von Aluminium und dessen Legierungen unter besonderer Berücksichtigung des Duralumins.

   Tests of an alloy of the duralumin type in which CO_2 snow was used as the cooling medium gave the following results:

Temperature (°F)	Tensile strength (lb/sq in.)	Elongation (percent) (1)
70	62,400	20.0
-110	67,300	22.5

[1]Gage length not given, probably $11.3\sqrt{a}$.

2. Sykes, W. P.:
Trans. Am. Inst. Mining and Metallurgical Eng., vol. 64, 1920, pp. 780-814

Effect of Temperature, Deformation, Grain Size, and Rate of Loading on Mechanical Properties of Metals.

This paper describes the tests of an aluminum alloy containing 3 percent copper, 0.42 percent iron, and 0.21 percent silicon in the form of wire 0.025 inch in diameter. The results were as follows:

Temperature (°F)	Tensile strength	
	Annealed wire (lb/sq in.)	Cold-drawn wire (lb/sq in.)
77	23,000	50,000
-300	37,000	63,000

3. Anon:
Reports of the Light Alloys Sub-Committee. Rep. No. 6, British A.C.A., 1921, pp. 91-106

Report of the Effect of Low Temperature on Some Aluminum Casting Alloys.

The following paragraph is quoted from the summary of tests made at the National Physical Laboratory in England. Sand-cast and chill-cast aluminum alloys of the types commonly used during the World War (1914-18) for aircraft-engine castings were used in these tests.

"The results of the tests indicate clearly that there is no marked decrease in the strength of any of these alloys when they are exposed to low temperatures, either while the alloys are at the low temperatures or when they are subsequently allowed to regain ordinary temperatures. On the contrary, it is found that at these low temperatures the alloys are markedly stronger, but that the strength becomes normal when they are again raised to ordinary atmospheric temperature."

4. Guillet, Léon, and Cournot, Jean: Revue de Métallurgie, vol. XIX, no. 4, April 1922, pp. 215-221

Sur la variation des propriétés mécaniques de quelques métaux et alliages aux basses températures.

Hardness and impact tests made on a duralumin type alloy with liquid air as the cooling medium gave the following results:

Temperature (°F)	Brinell hardness number	Impact resistance of Mesnager specimen in Guillery machine (ft-lb)
68	101	5.0
-310	129	5.6

5. Strauss, J.: Trans. Am. Soc. Steel Treating, vol. 16, no. 2, Aug. 1929, pp. 191-226

Metals and Alloys for Industrial Applications Requiring Extreme Stability.

Tensile tests on duralumin, in which liquid air was used as the cooling medium, gave the following results:

Temperature (°F)	Tensile strength (lb/sq in.)	Yield strength (lb/sq in.)	Elongation in 2 in. (percent)	Reduction of area (percent)
70	57,000	35,400	26.5	27.0
-310	71,800	42,700	28.0	28.7

6. Schwinning, W., and Fischer, F.: Zeitschr. f. Metallkunde, Bd. 22, No. 1, Jan. 1930, pp. 1-7.

Versuche über den Einfluss der Temperatur auf Kerbzähigkeit und Härte von Aluminiumlegierungen.

Report on hardness and impact tests on notched bars of Lautal and 99.5 percent aluminum. The following table summarizes the results:

Alloy	Temperature (°F)	Brinell hardness number	Impact strength (m-kg/cm²)
99.5 percent aluminum	68	30.4	4.0
	-105	36.0	----------
	-306	---------	6.1
Lautal	68	110.0	1.5
	-105	115.0	----------
	-306	---------	1.7

7. Güldner, W. A.: Zeitschr. f. Metallkunde, Bd. 22, No. 8, Aug. 1930, pp. 257-260.

Uber die Kerbzähigkeit einiger Aluminiumlegierungen insbesondere bei tiefen Temperaturen.

This author found improvement in the impact behavior of a few aluminum alloys at -75° F.

8. Pester, Fr.:
Zeitschr. f. Metallkunde, Bd. 22, No. 8, Aug. 1930, pp. 261-263

Die Festigkeitseigenschaften von elecktrischen Leitungsdrähten bei tiefen Temperaturen.

Pester found increases in tensile strength for aluminum conductor wire at -76° F.

9. Templin, R. L., and Paul, D. A.:
Symposium on Effect of Temperature on the Properties of Metals, issued jointly by A.S.T.M. and A.S.M.E. 1931

Mechanical Properties of Aluminum and Magnesium Alloys at Elevated Temperatures.

Tests made at the Aluminum Research Laboratories on various aluminum alloys cooled in a mixture of solid CO_2 and ether gave the following results:

Alloy	Temperature (°F)	Tensile strength (lb/sq in.)	Yield strength (lb/sq in.) (1)	Elongation in 2 in. (percent)
2SO	70 -110	13,250 15,180	4,150 4,150	41.5 47.5
2SH Rod	70 -110	23,460 24,720	19,700 21,350	16.0 18.0
3SH Rod	70 -110	28,730 31,940	25,300 28,200	10.0 12.5
17S-T Rod	70 -110	68,000 70,000	45,500 46,500	15.0 16.0
No. 43 sand cast	70 -110	20,050 20,180	8,000 8,000	4.5 5.0
No. 195-4 sand cast, heat treated	70 -110	35,145 36,830	23,250 25,200	4.5 4.0

[1]Offset = 0.1 percent.

10. Matthaes, K.:
Zeitschr. f. Metallkunde, Bd. 24, No. 8, Aug. 1932, pp. 176-180

Dynamische Festigkeitseigenschaften einiger Leichtmetalle.

This author found increases in impact strength for some aluminum alloys at -110° F and no change from room temperature values at -290° F.

11. Johnson, J. B., and Oberg, Ture:
Metals and Alloys, vol. 4, no. 3, March 1933, pp. 25-30

Mechanical Properties at Minus 40 Degrees of Metals Used in Aircraft Construction.

In tests made in the mechanically refrigerated cold room at Wright Field, duralumin rod and forgings showed the following results:

Temperature (°F)	Tensile strength (lb/sq in.)	Yield strength (lb/sq in.) (1)	Elongation in 4D (percent)	Izod impact (ft-lb) (2)	Endurance limit (lb/sq in.) (3)
Forging					
70	55,500	30,000	16	13	13,000
-40	58,500	31,500	13	13	16,000
Rod					
70	58,000	42,000	23.0	-------	----------
-40	60,500	44,500	23.5	-------	----------

[1] Offset = 0.2 percent.
[2] 45° V notch, 0.01-inch radius.
[3] Rotating beam, 500,000,000 cycles.

12. Schwinning, W.: VDI Zeitschr., Bd. 79, Nr. 2, Jan. 1935, pp. 35-40 — Die Festigkeitseigenschaften der Werkstoffe bei tiefen Temperaturen.

The results given in this paper are tabulated as follows:

Alloy	Temperature (°F)	Tensile strength (lb/sq in.)	Yield strength, set = 0.2 percent (lb/sq in.)	Elongation in 25 cm (percent)	Fatigue strength, 10^6 cycles (lb/sq in.)
Pure aluminum (99.5 percent) hard drawn	68	21,000	18,600	14	12,000
	-40	23,000	19,800	11.3	12,800
Aldrey	68	42,000	37,000	12.7	16,000
	-40	44,500	38,000	11.6	18,500
Bondur	68	64,000	48,000	18.8	20,000
	-40	65,000	48,400	19.9	16,300
Duralumin 681 B	68	61,500	49,000	16.9	18,000
	-40	63,000	49,600	15.0	18,000
Duralumin DM31	68	71,000	57,000	16.3	20,000
	-40	74,000	56,000	17.1	20,000

13. Boone, W. D., and Wishart, H. B.: A.S.T.M. Proc., vol. XXXV, pt. II, 1935, pp. 147-155 — High-Speed Fatigue Tests of Several Ferrous and Non-Ferrous Metals at Low Temperatures.

Rotating-beam fatigue tests made in the cold room at Wright Field on duralumin specimens indicate the following:

Temperature (°F)	Endurance limit based on 50,000,000 cycles (lb/sq in.)
80	17,000
-40	21,000

14. Moore, H. F., Wishart, H. B., and Lyon, S. W.: A.S.T.M. Proc., vol. XXXVI, pt. II, 1936, pp. 110-117

Slow-Bend and Impact Tests of Notched Bars at Low Temperatures.

Tests made on 17S-T rod in one of the cold rooms at Wright Field have shown the following results:

Temperature (°F)	Slow bend tests energy for fracture (ft-lb)	Impact tests energy for fracture (ft-lb) (1)
70	13.00	18.10
-40	13.82	19.60

[1]Izod test, specimen with 45° V notch, 0.01-inch radius.

15. Bungardt, K.: Zeitschr. f. Metallkunde, Bd. 30, No. 7, July 1938, pp. 235-237

Dynamische Festigkeitseigenschaften von Leichtmetall-Legierungen bei tiefen Temperaturen.

Tests made in Germany on duralumin rod and sheet showed the following results:

Temperature (°F)	Endurance limit (lb/sq in.) (1)	Notched bar impact (m-kg/cm²)
68	23,000	0.96
-85	27,000	1.32

[1]Rotating beam machine using 20,000,000 cycles.

16. NACA Annual Reports: 1936, 1937.

The Twenty-second and Twenty-third Annual Reports of the National Advisory Committee for Aeronautics comment briefly on a program of tests carried out by the National Bureau of Standards in cooperation with the Bureau of Aeronautics on various aircraft metals at sub-zero temperatures. The program involved what appears to have been an extensive study of properties and impact resistance. The following quotation is taken from the Twenty-third Annual Report, page 32:

"The only important adverse effect of low temperature, down to -80° C [-112° F], is the decreased impact resistance of ferritic steels, which is in marked contrast to the aluminum alloys and the austenitic steels."

17. Rosenberg, Samuel J.: Res. Paper 1347, Nat. Bur. of Standards Jour. Res., vol. 25, no. 6, Dec. 1940, pp. 673-701

Effect of Low Temperatures on the Properties of Aircraft Metals.

The conclusions of

this report include the following quotation:

"The effect of sub-zero temperatures down to -78° C [-109° F] was determined on the tensile, hardness, and impact properties of metals commonly used in aircraft construction.

"The tensile properties and the hardness of all materials were generally improved at low temperatures . . . . . The impact resistance of the aluminum-base alloys was not decreased; . . ."

18. Gillett, H. W.: Book prepared for Project 13 of the Joint A.S.T.M.-A.S.M.E. Research Committee on Effect of Temperature on Properties of Metals, Aug. 1941. American Society for Testing Materials, Phila., Pa.

Impact Resistance and Tensile Properties of Metals at Subatmospheric Temperatures.

This book summarizes data, both published and unpublished, from numerous sources. Tables 125, 133, and 134 deal specifically with aluminum alloys, and the text, in reference to these tables, states:

"All these non-ferrous alloys are shown to have very closely the same properties at -40° F as at room temperature.

"No deterioration in properties is met at -105° F in these wrought alloys . . . the determinations at -105° F could be taken as checking the room temperature figures."

TESTS ON SOLID ROUND RODS AT -120° F

In all the foregoing investigations the materials were in the form of small laboratory specimens. In order to demonstrate the ability of the various aluminum alloys to withstand severe shock loads at low temperatures in larger size pieces, a series of tests were made on 2-inch solid round rods subjected to the blow of a 500-pound tup striking at the center of a 36-inch span. All tests were conducted under the outdoor impact test tower at Aluminum Research Laboratories and for the low temperature tests the specimens were cooled to a temperature of -120° F by use of a mixture of dry ice and kerosene. Figure 1 shows the six specimens following the low temperature drop tests. The height of drop used in each case and the permanent sets, both at ordinary temperature and at low temperature, are given in the following table:

Alloy	Height of drop of 500-lb tup (in.)	Permanent set (in.)	
		Rod at 75° F	Rod at -120° F
27S-T	120	4 5/8	4 3/4
17S-T	96	4 1/8	4 3/16
61S-T	96	5 1/4	5 1/4
A17S-T	84	5 1/2	5 5/16
53S-T	84	5 5/8	5 3/4
52S-1/4H	72	6	6

CONCLUSION

On the basis of the foregoing test results, it can be concluded that aluminum alloys, in general, either remain unchanged or show an improvement in strength and ductility when exposed to low temperatures.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Pa., December 10, 1941.

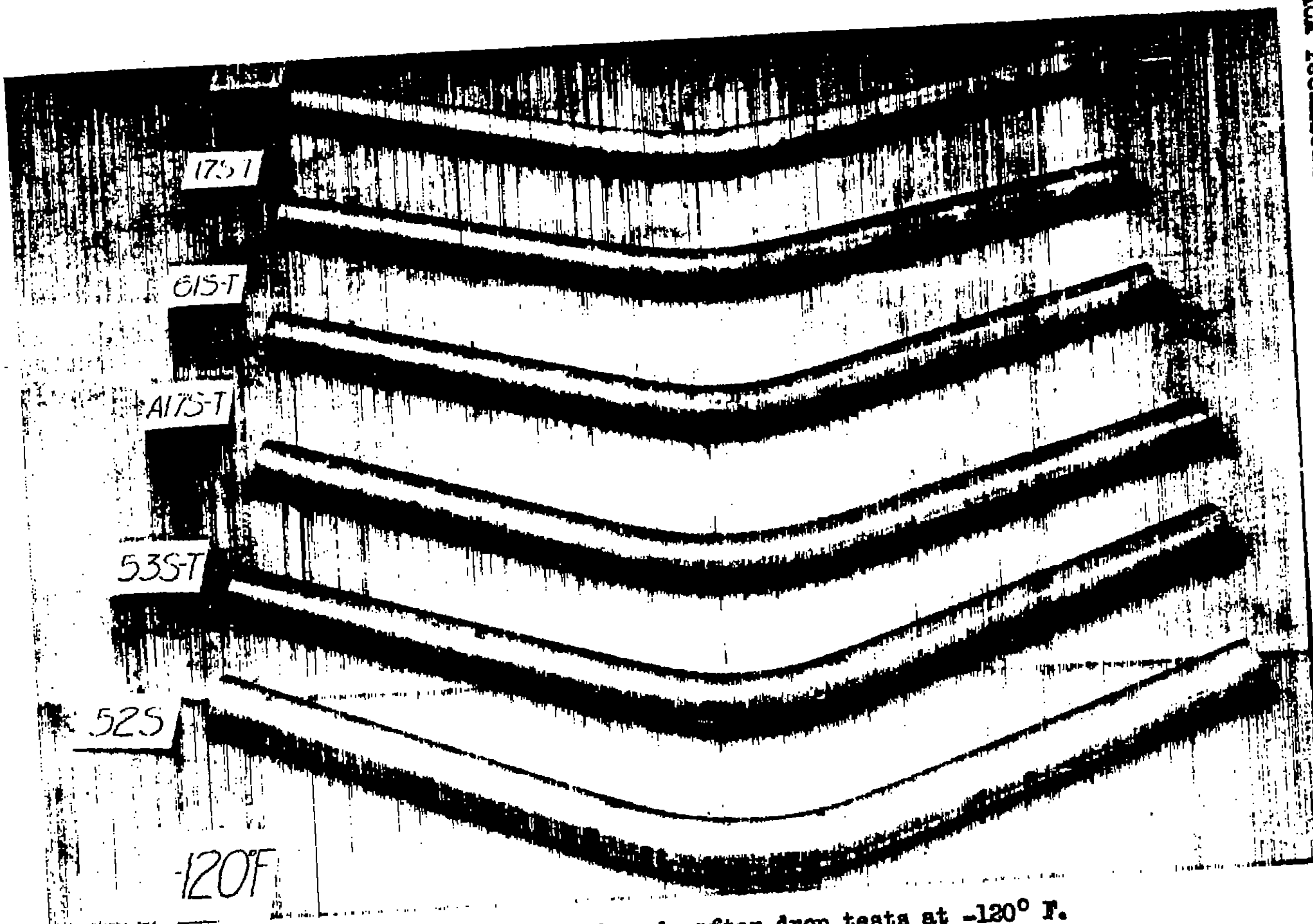

Figure 1.- The 2-inch rods after drop tests at -120° F.